REPORT DOCUMENTATION PAGE

AFRL-SR-BL-TR-02-

0037

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
		15 Dec 95 - 29 Jan 01

4. TITLE AND SUBTITLE
Center for Computational Electromagnetics of Complex Structures

5. FUNDING NUMBERS
F49620-96-1-0025

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AFOSR/NM
801 N. Randolph Street Room 732
Arlington, VA 22203-1977

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
F49620-96-1-0025

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

12b. DISTRIBUTION CODE

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13. ABSTRACT *(Maximum 200 words)*

On the frequency domain fast solvers front, we have: We have continued our focus on improving the Fast Illinois Solve Code (FISC) which has a user base of over 400 distributed by SAIC/DEMACO. To stress the code for large scale computing, we put FISC through a number of tour de force computations. Recently, we have put F]SC through a broad bandwidth calculation where we can simulate the time-domain scattering from a fill-size aircraft with frequency content up to 1 GHz. We continued to make progress with the parallelization of MLFMA with the development of ScaleME. By the end of April of 2001, ScaleME was able to solve a 10 million unknown problem. The code is about 7-9 times faster that FISC (Fast Illinois Solver Code) that solved a similar size problem about over two year ago. The speedup compared to FISC essentially comes from the good scaling property of ScaleME for massively parallel computing. We used 128 processors on the NCSA 561 02K. In addition, we have looked at ways to solve Maxwell's equations with fast solvers all the way from static to microwave frequencies. This simulation capability will encompass circuit theory as a special case, allowing antenna impedances and circuit phenomena to he more accurately modeled. We have also developed a new fast solver when the scatterer is placed on top, or embedded in a layered earth. This capability will have significance in studying the radar returns from targets placed under tree canopy, or in studying scattering from buried objects. With this code, we can solve problems with over a million unknowns easily.

14. SUBJECT TERMS

15. NUMBER OF PAGES
13

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECU... OF TI...		20. LIMITATION OF ABSTRACT

20020215 104

Standard Form 298 (Rev. 2-89) (EG)
Prescribed by ANSI Std. 239.18
Designed using Perform Pro, WHS/DIOR, Oct 94

FINAL PROGRESS REPORT

FOR CENTER FOR COMPUTATIONAL ELECTROMAGNETICS OF COMPLEX STRUCTURES

Due: December 31, 2001

Title: Center for Computational Electromagnetics of Complex Structures

Contract Number: F49620-96-1-0025

Progress Report:

1 Aug 00 - 31 July 01

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OBJECTIVES

The objective of our research effort is to develop a knowledge base in computational electromagnetics that can impact a wide variety of technologies. To achieve this objective we will perform basic research on two fronts:

- Fast integral equation solvers for analyzing scattering and propagation problems in a numerically exact manner with reduced computational complexity and memory requirements.
- Accurate partial differential equation solvers that minimize grid-dispersion errors, and that are devoid of spurious solutions.

In addition, we will augment the above by hybridizing differential equation and integral equation solvers to exploit their respective strengths. This will allow us to solve scattering problems involving complex environments like a scatterer buried in an inhomogeneous, anisotropic media.

In order to seek the solution of extremely large or quasi-optical problems, we will hybridize the aforementioned solvers with high-frequency methods such as the shooting and bouncing ray (SBR) method that is used in XPATCH.

The multiple scattering T matrix approach has been used to analyze scattering from a large number of randomly distributed particles. We will improve on this algorithm for particles of complex shapes and use

the resulting codes to calculate parameters for the elements of Mueller matrices to be used in transport equation like the radiative transfer equation for simulation of wave propagation through random media.

Finally, to harness maximally the throughput of modern computers, we will seek the parallelization of the aforementioned algorithms on massively parallel processor (MPP) machines. This will allow us to solve problems of unprecedented sizes and complexities.

At UT Austin, the scientific objective of this research unit is to develop postprocessing algorithms that are tightly coupled to CEM engines to enhance phenomenology understanding and provide linkage to the end user community. In particular, we are addressing postprocessing issues in both radar signature prediction and antenna design for complex platforms. In the signature prediction area, we are developing extrapolation and interpolation algorithms in frequency and angle to accelerate the generation of range profiles and inverse synthetic aperture radar (ISAR) imagery using the Fast Illinois Solver Code (FISC). In the antenna design area, we are developing the antenna synthetic aperture radar (ASAR) concept to pinpoint locations of dominant antenna-platform interaction from CEM data.

STATUS OF EFFORT/ACCOMPLISHMENTS/NEW FINDINGS

On the frequency domain fast solvers front, we have:

- We have continued our focus on improving the Fast Illinois Solve Code (FISC) which has a user base of over 400 distributed by SAIC/DEMACO. To stress the code for large scale computing, we put FISC through a number of tour de force computations. Recently, we have put FISC through a broad bandwidth calculation where we can simulate the time-domain scattering from a full-size aircraft with frequency content up to 1 GHz.
- We continued to make progress with the parallelization of MLFMA with the development of ScaleME. By the end of April of 2001, ScaleME was able to solve a 10 million unknown problem. The code is about 7-9 times faster that FISC (Fast Illinois Solver Code) that solved a similar size problem about over two year ago. The speedup compared to FISC essentially comes from the good scaling property of ScaleME for massively parallel computing. We used 128 processors on the NCSA SGI O2K.
- In addition, we have looked at ways to solve Maxwell's equations with fast solvers all the way from static to microwave frequencies. This simulation capability will encompass circuit theory as a special case, allowing antenna impedances and circuit phenomena to be more accurately modeled.
- We have also developed a new fast solver when the scatterer is placed on top, or embedded in a layered earth. This capability will have significance in studying the radar returns from targets placed under tree canopy, or in studying scattering from buried objects. With this code, we can solve problems with over a million unknowns easily.

In the time domain and genetic algorithm fronts, the progress are:

- A new PWTD kernel suitable for the analysis of low frequency problems was developed. Just like all all fast multipole like schemes, the classical PWTD kernel suffers from a "low frequency breakdown problem". This new kernel effectively resolves this issue wiityhin the context of PWTD schemes.
- A new low frequency PWTD enhanced time domain integral equation solver was developed. This new solver relies on loop tree decompositions and permits the analysis of transients on electrically small structures using very large CFL numbers.
- A new PWTD enhanced time domain integral equation solver for lossy penetrable media was developed. When hybridized with our previous PWTD solvers for perfectly conducting scatterers this new solver will permit the analysis of scattering from coated structures.
- Inroads were made in the development of PWTD schemes for analyzing layered media problems.
- New FFT-based time domain integral equation solvers were developed. These solvers constitute extensions of the adaptive integral equation scheme to the time domain. While these solvers are not expected to compete with PWTD solvers when applied to the analysis f arbitrarily shaped structures,

they do compete favorably with PWTD technology when the scatterer is a penetrable volume and/or quasi-planar.

On higher-order methods for computational electromagnetics, we have:

- Developed a time-domain finite element method (TDFEM) for scattering and radiation analysis. In this work, we have (1) developed a set of novel orthogonal vector basis functions which yield a diagonal mass matrix thus avoiding a matrix inversion in each time step, (2) developed a general approach to investigate the stability of the TDFEM approaches and estimate the maximum time step for conditionally stable TDFEM schemes, (3) developed an approach to deal with dispersive media which enables wideband simulations, (4) developed a perfectly matched layers (PML) for the TDFEM simulation of open-region problems, and (5) developed a hybrid approach that combines the TDFEM and time-domain integral equation (TDIE) methods for scattering and radiation analysis.
- Developed a novel hybridization for the high-order finite element method and a high-order multilevel fast multipole algorithm (MLFMA) for scattering by complex targets with complex material compositions. The hybrid method starts from an absorbing boundary condition and iteratively constructs an adaptive absorbing boundary condition that is numerically exact for a given problem. Since it solves only a purely sparse finite element matrix, its efficiency is at least an order of magnitude higher than traditional finite element--boundary integral methods.
- Developed a novel physics-based preconditioner for the finite element--boundary integral method. Instead of using a mathematical preconditioner, this method construct a preconditioner using an appropriate absorbing boundary condition. By using a Krylov subspace-based iterative slover, it can achieve a speedup of more than two orders of magnitude over the tradiational finite element--boundary integral methods, especially when high-order discretization is used.
- Developed a high-order multilevel fast multipole algorithm (MLFMA) for scattering by objects that consist of both perfect electric conductors and piecewise homogeneous materials. This method is based on the PMCHWT formulation for the fields in penetrable regions and the combined field integral equation for conducting regions. It permits the simulation of complex targets such as coated objects.

On the post-processing front done at UT Austin, we have:

- A preconditioner based on the wavelet basis has been developed to accelerate the convergence of iterative solvers for large-scale three-dimensional problems. Numerical results on a 3-D cavity showed that the wavelet preconditioner outperform the traditional space-domain block-banded preconditioner. The computational cost of the preconditioner can be kept under $O(N\log N)$, making it compatible with the multi-level fast multipole method.
- The antenna-platform interaction problem has been extended to account for both array mutual coupling and platform effects. A sparse model to describe the active element patterns of an array has been developed, and an algorithm to extract the model parameters has been devised. Simulation results using the latest FISC-radiation code showed that the model can accurately represent very complex array responses. Measurements were conducted using a 7-element smart antenna testbed at the University of Texas to verify the simulation.

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40. K. Aygun, M. Lu, B. Shanker, and E. Michielssen, "Analysis of PCB level EMI phenomena using an adaptive low-frequency plane wave time domain algorithm," Proceedings of the 2000 IEEE Int. Symp. On EMC, Washington DC, vol. 1, pp. 295-300, August 21-25, 2000, (invited).
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51. M. Lu and E. Michielssen "A Marching-on-in-Time Based Transient Electric Field Integral Equation Solver for Microstrip Structures", Proceedings of the 2001 IEEE International Antenna and Propagation Symposium, Boston, MA, July 2001, accepted for publication.
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60. J. M. Jin, F. Ling, and D. Jiao, "Fast analysis of microstrip antennas and arrays," 17th Annual Review of Progress in Applied Computational Electromagnetics, Monterey, CA, March 2001.
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64. K. Dandekar, H. Ling and G. Xu, "Smart antenna calibration procedure including amplitude and phase mismatch and mutual coupling effects," 2000 IEEE International Conference of Personal Wireless Communications, vol. 1, pp. 293-297, Hyberadad, India, December 2000.
65. H. Choo and H. Ling, "Design of dual-band microstrip antennas using the genetic algorithm," 17th Annual Review of Progress in Applied Computational Electromagnetics, pp. 80-88, Monterey, CA, March 2001.

INTERACTIONS/TRANSITIONS

- Participation/Presentations At Meetings, Conferences, Seminars, Etc

Unpublished Presentations

1. W.C. Chew, "Fast Solvers for Electromagnetic Simulations-A New Age Analysis Tool," National

University of Singapore, Singapore, August 10, 2000.

2. W.C. Chew, "Fast Solvers for Electromagnetic Simulations-A New Age Analysis Tool," City U Hong Kong, August 21, 2000.
3. W.C. Chew, "Modern Radar Technology and Electromagnetic Simulations," Champaign County Rotary Club, Monticello, Illinois, September 20, 2000.
4. W.C. Chew, "Overview of Center for Computational Electromagnetics," SAIC Presentation to Senator Durbin, Champaign, Illinois, August 30, 2000.
5. W.C. Chew, "Radar signature as a way to identify aircraft," Rotarian Club of Monticello, Illinois, September 20, 2000.
6. W.C. Chew, "Overview of Center for Computational Electromagnetics," SAIC Presentation to CEO Steve Rockwood, Champaign, Illinois, October 4, 2000.
7. W.C. Chew, "Fast Solvers in Computational Electromagnetics," Presentation to College of Engineering Advisory Board, UIUC, October 6, 2000.
8. W.C. Chew, "Fast Solvers in Computational Electromagnetics—Physics, Mathematics, and Computer Science," CEPS Industry Affiliates Program Workshop, UIUC, October 12, 2000.
9. W.C. Chew, "Recent Advances in Fast Solvers in Computational Electromagnetics," Technical Forum at IBM, Yorktown Heights, October 13, 2000.
10. W.C. Chew, "Fast Solvers in Computational Electromagnetics," Intel Corporation, Santa Clara, CA, December 14, 2000.
11. W.C. Chew, "Fast Solvers in Computational Electromagnetics," Sun Microsystem, San Jose, CA, December 15, 2000.
12. W.C. Chew and B. Hu, "Fast Algorithm for Layered Media," AFOSR Electromagnetic Workshop, San Antonio, TX, January 11, 2001.
13. W.C. Chew, B. Hu and C. Pan, "Fast Inhomogeneous Plane Wave Algorithm for Layered Media," Hanscom AFB, Bedford, MA, February 23, 2001.
14. W.C. Chew, "Fast Algorithms for Electromagnetic Simulation," Texas A&M Distinguished Speaker, April 5, 2001.
15. W.C. Chew, "Recent Progress in Computational Electromagnetics," EMCC 2001, Kauai, HI, May 30, 2001.
16. W.C. Chew, "Fast Algorithms for Computational Electromagnetics, and Inverse Scattering Problems," Tohoku University, Sendai, Japan, Aug 3, 2001.
17. W.C. Chew, "Lectures in Fast Algorithms and Inverse Problems," National University of Singapore, Aug 6-10, 2001.
18. W.C. Chew, "Inverse problems and the processing of the VETEM data," INEEL, Idaho Falls, Idaho, Aug 15, 2001.
19. W.C. Chew, "Fast algorithms for large scale computing in CEM," US Army Research Lab, Baltimore, MD, Nov 6, 2001.
20. E. Michielssen, "Fast Integral Equation Methods for Wave Transients," MIT Distinguished Speaker Series in High Performance Computation for Engineered Systems, October 18, 2000.
21. E. Michielssen, Fast integral equation solvers for computational electromagnetics," Computational Electromagnetics Workshop, Royal Institute of Technology, Stockholm, Sweden, December 7, 2000.
22. E. Michielssen, Institute for Pure and Applied Mathematics, UCLA, Workshop, May 18, 2001
23. E. Michielssen, Department of Electronic Engineering, Tel Aviv University, July 4, 2001
24. E. Michielssen, Applied Mathematics Colloquium, Department of Applied Mathematics, Caltech, November 19, 2001
25. J. M. Jin, "Fast Algorithms for Electromagnetic Modeling of Microstrip Problems," Third H-Infinity Workshop of the Defense Research Initiative Program, Annapolis, VA, Oct. 2000.

- Consultative And Advisory Functions To Other Laboratories And Agencies

Worked with MSRC at WPAFB to install a copy of FISC on their supercomputer (W. Chew).

Visited Jeff Hughes and Chief Scientist at WPAFB (W. Chew).

Interacted with Raju Numburu at ARL, Adelphi, Maryland. (W. Chew)

Interacted with Joe Shang at WPAFB, Dayton. (W. Chew)

Evaluation of Enigineering Program, National University of Singapore (W. Chew)

Evaluation of EE Program at City U of Hong Kong (W. Chew)

Fast Solvers for Electromagnetics (W. Chew)
DEMACO, Champaign, IL
Dr. D. Andersh

Worked with Lockheed Martin Corporation to transfer the inlet-simulation technology to industry (J. Jin).

- Transitions

We are working with DEMACO to produce an industrial strength CEM code using the multilevel fast multipole algorithm that can solve complex structures. We call this code FISC (Fast Illinois Solver Code). We hope to add new features to the code to enhance its capability. Many copies of the code have been distributed to DOD Laboratories and industry shortly. FISC has been distributed to over 400 government labs, agencies, and industries.

Fast solver and genetic algorithm technology was used for designing log-periodic antennas for DARPA's FOPEN project – this work was carried out in collaboration with Lockheed Martin Corporation.

Lockheed Martin and Mission Research Corporation are working with UIUC to transition technologies developed at CCEM to the industries.

NEW DISCOVERIES, INVENTIONS, OR PATENT DISCLOSURES

- Developed FISC to a higher level of sophistication with reduced setup time, and capability to solve poblems with close to 10 million unknowns as well as performing broadband time domain computation.
- Implemented a highly portable and parallel version of multilevel fast multipole algorithm (MLFMA) and tested on SGI Array and Linux cluster solving problem up to 10 million unknowns.
- Developed a new fast algorithm for layered media using fast inhomogeneous plane wave algorithm.
- Developed a high-order time-domain finite element method.
- Developed a novel preconditioner for the finite element--boundary integral method.
- Developed multilevel plane wave time-domain algorithms for analyzing large scale acoustic scattering phenomena, and electromagnetic phenomena involving perfectly conducting as well as penetrable targets.
- Developed fast global boundary conditions for FDTD simulations based on PWTD technology.
- Developed PWTD based techniques for analyzing nonlinear phenomena.
- Developed diploidy GAs for controlling adaptive antennas.
- Developed multiparameter model-order reduction techniques.
- Developed low-frequency methods both in the time and the frequency domain.
- Developed higher-order accurate MOM and FEM methods.
- Developed efficient method for the engine inlet problem.
- H. Choo and H. Ling, "Microstrip antennas and methods of designing same," provisional patent application, docket no. 5119-09201, submitted December 2001.

HONORS/AWARDS

- C. Pan, EPEP Best Student Paper Award, 2001.
- M.Y. Lu, APS Best Student Paper Award, 2001.

- Jianming Jin---2001 IEEE Fellow.
- Eric Michielssen---2001Senior Xerox Award for Faculty Research, UIUC
- Eric Michielssen---2001-2002 Beckman Associate, Center for Advanced Studies, UIUC
- W.C. Chew---2001, Campus Wide Excellence in Professional and Graduate Teaching.
- W.C. Chew---2001, S.A. Schekulnoff Best Paper Award, AP Transaction (coauthored with J.S. Zhao).